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Phosphorus recovery and recycling from waste: An appraisal based on a French case study

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ABSTRACT

Phosphate rocks, used for phosphorus (P) fertilizer production, are a non-renewable resource at the human time scale. Their depletion at the global scale may threaten global food and feed security. To prevent this depletion, improved P resource recycling from food chain waste to agricultural soils and to the food and feed industry is often presented as a serious option. However, waste streams are often complex and their recycling efficiency is poorly characterized. The aim of this paper is to estimate the P recovery and recycling potential from waste, considering France as a case study. We assessed the P flows in food processing waste, household wastewater and municipal waste at the country scale using a substance flow analysis for the year 2006. We also quantified the P recycling efficiency as the fraction of P in waste that ultimately reached agricultural soils or was recycled in the food and feed industry. Efforts were made to limit data uncertainty by cross-checking multiple data sources concerning P content in waste materials. Results showed that, in general, P recovery in waste was high but that the overall P recycling efficiency was only 51% at the country scale. In particular, P recycling efficiency was 75% for industrial waste, 43% for household wastewater and 47% for municipal waste. The remaining P was discharged into water bodies or landfilled, causing P-induced environmental problems as well as losses of nutrient resources. Major P losses were through food waste (which amounted to 39% of P in available food) and treated wastewater, and the findings were confirmed through cross-checking with alternative data sources. Options for improving P resource recycling and, thereby, reducing P fertilizer use were quantified but appeared to be less promising than scenarios based on reduced food waste or redesigned agricultural systems.

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1. Introduction

Phosphorus (P) plays a key role in sustainable food, feed, biofuel and fiber production. It is generally applied to agricultural soils through chemical P fertilizers. Such fertilizers are produced from phosphate rock. However, the supply of phosphate rock is limited at the global scale (Cordell et al., 2011, 2009; Smil, 2000). Currently, 178.5 Mt of phosphate rock, equivalent to 23 Mt of P, is being mined every year, of which 90% is used for food production as fertilizer (approx. 82%) and feed additives (approx. 7%) (IFA, 2011). Due to the increase in food and feed demand, phosphate rock is expected to become increasingly scarce and expensive in the coming years (Cordell et al., 2009). Furthermore, phosphate rock deposits are very unequally distributed since more than 85% of this resource is controlled by only three countries (Morocco, China and the USA) (Van Vuuren et al., 2010). This may lead to severe geopolitical issues on P fertilizer availability and, in turn, on regional food production and food security (Dumas et al., 2011).

Preventing such depletion means limiting P losses and increasing P resource recycling along the food chain. Although rock phosphates are non-renewable at the human time scale, P as an element is recyclable since most of the P used for food production finally ends up in different waste systems, except for the P that becomes fixed in agricultural soils. Recent global phosphorus

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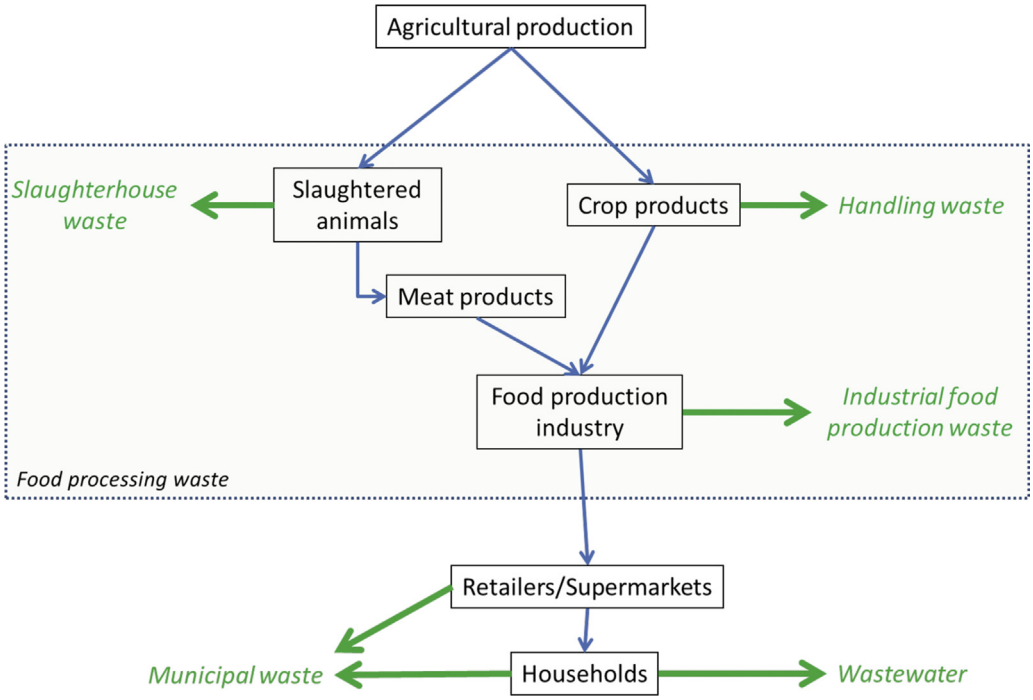

Fig. 1. Representation of the waste streams considered in this study.

analyses have highlighted the key role played by the waste sector in P resource recycling (Elser and Bennett, 2011). A recent study has reported that, if collected, the P available from human urine and feces could account for 22% of the global P fertilizer demand (Mihelcic et al., 2011). However, many studies have reported low efficiencies of current waste management systems in recovering and recycling P from waste (Antikainen et al., 2005; Neset et al., 2008; Kalmykova et al., 2012). At the global scale, it is estimated that only 10–50% of P in human excreta is recycled to agricultural soils (Liu et al., 2008; Cordell et al., 2009), leading to large P losses through wastewater or municipal solid waste. These studies conclude that progress in that domain would help to achieve a better closed-loop P cycle and to meet future P demand (Cordell et al., 2011; MacDonald et al., 2012). However, waste streams are often multiple and complex and the related data are dispersed among many different sources. Moreover, availability of accurate figures is scarce in the area of P recovery and recycling from waste, thus creating uncertainty. In addition, waste stream recycling efficiency is often poorly assessed due to incomplete or inaccurate data sources (Cordell et al., 2012). There is, therefore, a need to better characterize these streams in order to assess to what extent the current and potential P recycling from these wastes could help to meet agricultural P demand. We developed such a characterization, using France as a case study, since it typically represents a Western country with a high P-input agriculture, a long food chain driven by affluent diets, and efficient, centralized waste collection and processing. The country scale offered opportunities to use consistent data sources and waste regulations.

The specific objectives of this study were: (1) to quantify P flows along the food processing, household wastewater and municipal waste chains at the country scale; (2) to quantify P recovery, P recycling and P losses at various stages of the waste streams; and (3) to identify opportunities for improved P resource recycling. A particular effort was made to estimate the overall consistency of the results through cross-checking with alternative, independent data sources about average food diets in France and P discharged into fresh water bodies.

2. Materials and methods

2.1. System design and study area

The P flows along the food processing waste, household wastewater and municipal waste chains were assessed using a Substance Flow Analysis (SFA) at the country scale for France (Fig. 1). The basic objective of the SFA method is to quantify the pathways of a substance in, out and through a geographically considered system (Brunner and Ma, 2008). This makes it possible to estimate how P flows through the waste system, thereby assessing the contribution of the different waste streams and prioritizing strategies for improved P recycling (Brunner, 2010; Cordell et al., 2012). In this paper, the substance flows were quantified as material flows multiplied by their respective P content. An estimation of the entire P socio-metabolism in France was presented in Senthilkumar et al. (2012a), whereas the present study focused on the waste management sectors in order to identify major P losses and opportunities for improving P recycling from waste. SFA was previously used to calculate P flows at global (Liu et al., 2008), national (Mishima et al., 2010) and regional (Senthilkumar et al., 2012b) scales. The fitness of SFA modeling applied to P in France was strong due to the availability of reliable, recent, detailed and consistent data from various official public databases (see Section 2.2). The geographical system boundaries of the SFA model were the land borders of France, excluding islands and overseas territories. P flows were quantified for the year 2006, which was the last year with complete datasets at the time of the study. The different types of waste as well as their recovery and recycling requirements are presented in Table 1.

2.2. Data collection and quantification of P flows

Data concerning the amount of material flows were collected from European and French databases: FAOStat (FAO, 2009), Eurostat (EUROSTAT, 2009), French Ministry of Agriculture and Food (AGRESTE, 2009), French Institute for the Environment (IFEN, 2009), French Agency for Environment and Energy (ADEME, 2010),

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